Simulated Synthesis Imaging of Geostationary Satellites

Henrique R. Schmitt[a], David Mozurkewich[b], Anders M. Jorgensen[c] Sergio R. Restaino[d], J. Thomas Armstrong[d], Ellyn K. Baines[d] and Robert B. Hindsley[d]

[a]Computational Physics, Inc., 8001 Braddock Rd, Springfield, VA 22151, USA;
[b]Seabrook Engineering, Seabrook, MD 20706, USA;
[c]Electrical Engineering Department, New Mexico Institute of Mining and Technology, Socorro, NM 87801, USA;
[d]Remote Sensing Division, Naval Research Laboratory, Washington, DC 20375, USA;

ABSTRACT

We simulate observations of a satellite using various optical interferometer configurations, and reconstruct images with aperture synthesis techniques from these simulated observations. We compare the typical Y-shaped interferometer design to arrays of 30 telescopes on either a redundant or a non-redundant hexagonal grid and to an array mounted on a linear movable boom, all with multiple spectral channels covering a broad wavelength range. We investigate the number of telescopes, the baseline lengths, and the configuration that retrieve the most accurate image relative to the original.

Keywords: geostationary satellites, optical interferometry imaging, telescope arrays

1. INTRODUCTION

Imaging of geostationary satellites is an important asset to diagnose problems with the instrument, deployment issues and other such problems. However, unlike low Earth orbiting satellites, resolution is a major issue for the case of geostationary satellites. Given their altitude of ∼36,000 km and sizes of ∼10 m, corresponding to an angle of 0.28μradian (∼58 milli arcseconds), even the largest ground based telescopes are not able to obtain a detailed image of these satellites. This indicates the need to use optical interferometers in order to obtain more detailed images. Here we present simulations of interferometric observations of a geostationary satellite with different optical interferometer arrays, and compare the performance of these arrays in recovering the satellite image. This paper is accompanied by 2 other papers (Refs.4,3), which do a more detailed description of one of these arrays and an analysis of the signal to noise and integration times needed to observe geostationary satellites with different magnitudes.

2. SIMULATED SATELLITE OBSERVATIONS

The simulations presented here were done using a simulated optical image of the satellite Gorizont (Ref. 2). The satellite was assumed to have a largest dimension of 15 meters, which corresponds to 0.4 μradians (86 milli arcseconds) and the geostationary altitude.

Four different array configurations were used in our simulations. Fig. 2 shows their layouts and corresponding uv-plane coverages (MTF). The Y-shaped array, has the same station distribution as the Navy Prototype Optical Interferometer (NPOI) Ref. 1. It is composed of 3 arms separated by 120° each, with the Northern one oriented at 6.3° West of North. The stations are located at roughly 2.8, 4.8, 7.6, 12.5, 20.6, 34.5, and 56.3m relative to the array center in each arm. The Northern arm has an extra station at 0.5 m and the Eastern one does not have the first station. This array has baselines with lengths between 2 and 98 meters. We also explored the case of a Y-shaped array with 12 telescopes, with maximum baseline lengths of 23 m. The movable boom with 9 telescopes following the station locations in the NPOI Northern arm has baselines with lengths between 2 and 92 m. We also simulated the case of a boom with only 6 telescopes and maximum baseline length of 23m. In

Further author information: (Send correspondence to H.R.S.)E-mail: hschmitt@ccs.nrl.navy.mil, Telephone: 1 202 767 2977

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE **Simulated Synthesis Imaging of Geostationary Satellites**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Computational Physics, Inc,8001 Braddock Rd,Springfield,VA,22151**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

AMOS, Advanced Maui Optical and Space Surveillance Technologies Conference, 12-16 Sep 2011, Maui, HI.

14. ABSTRACT

We simulate observations of a satellite using various optical interferometer configurations, and reconstruct images with aperture synthesis techniques from these simulated observations. We compare the typical Y-shaped interferometer design to arrays of 30 telescopes on either a redundant or a non-redundant hexagonal grid and to an array mounted on a linear movable boom, all with multiple spectral channels covering a broad wavelength range. We investigate the number of telescopes, the baseline lengths, and the configuration that retrieve the most accurate image relative to the original.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

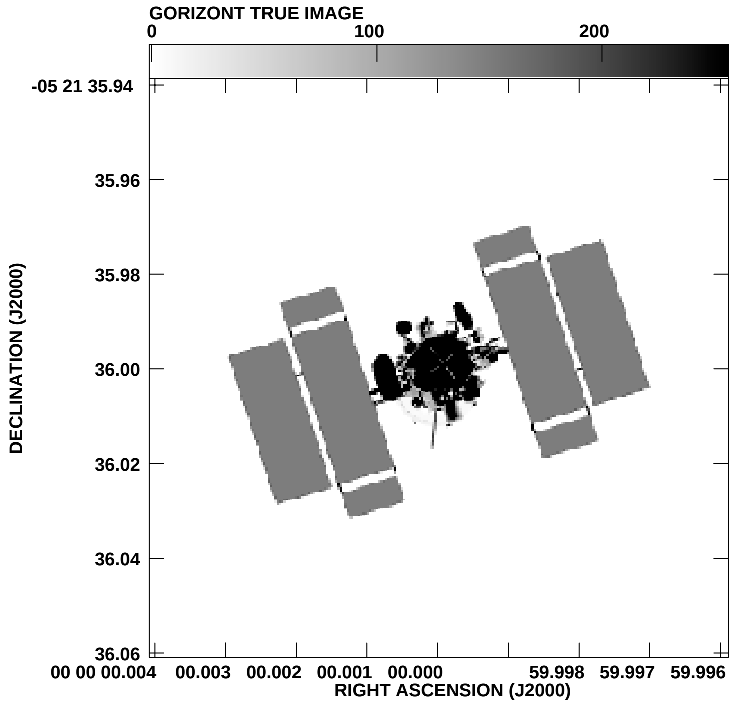

Figure 1. Simulated image of the satellite Gorizont. We assume that the satellite has a maximum size of 15 meters, which corresponds to 86 mas.

this case of the boom we simulated observations with the array being rotated in 36 steps of 5°, in order to cover the uv-plane.

The other two arrays considered are composed of 30 telescopes each, arranged on a hexagonal grid, which produce a non-redundant and a redundant uv-coverage. These arrays have a shortest baseline of 2m and a longest baseline of 43 and 24 m, respectively. Mozurkewich et al. (2011)[4] and Jorgensen et al. (2011)[3] present results related to the non-redundant array in better detail.

We used these array configurations and the radio software AIPS[6] to simulate the interferometric observations. We assumed a system similar to the one currently available at the NPOI, where we simultaneously observe 16 channels in the wavelength range 480-850 nm. We use channels with a constant width of 16.7 THz (13 nm at 480 nm, increasing to 40 nm at 850 nm). The image reconstruction was also done in AIPS using the task IMAGR. The reconstructed images have 256×256 pixels with a dimension of 0.476 mas each. The simulations presented here are noiseless, but Jorgensen et al. (2011)[3] discusses the expected signal to noise level and integration times for different satellite magnitudes, in the case of the non-redundant array with 30 telescopes. See Ref.[5] for a larger number of simulations, including different arrays.

3. IMAGING RESULTS

We present in Figs. 3,4 the images obtained with the different arrays, and the corresponding fractional residual images. The fractional residual images were created by dividing the difference between the synthesized image and the true one, convolved to the same resolution, by the true image. An inspection of the images shows that all the configurations do a good job of recovering the satellite images, although with different resolutions and levels of accuracy. In the case of the Y-shaped array and the boom with maximum baselines of ∼90 m, corresponding to a resolution of 20 cm at the Geo altitude, the Y-array produces images with smaller residuals. However, when we shorten these arrays to ∼20 m, corresponding to a resolution of ∼1 m, the opposite is true. This is due to

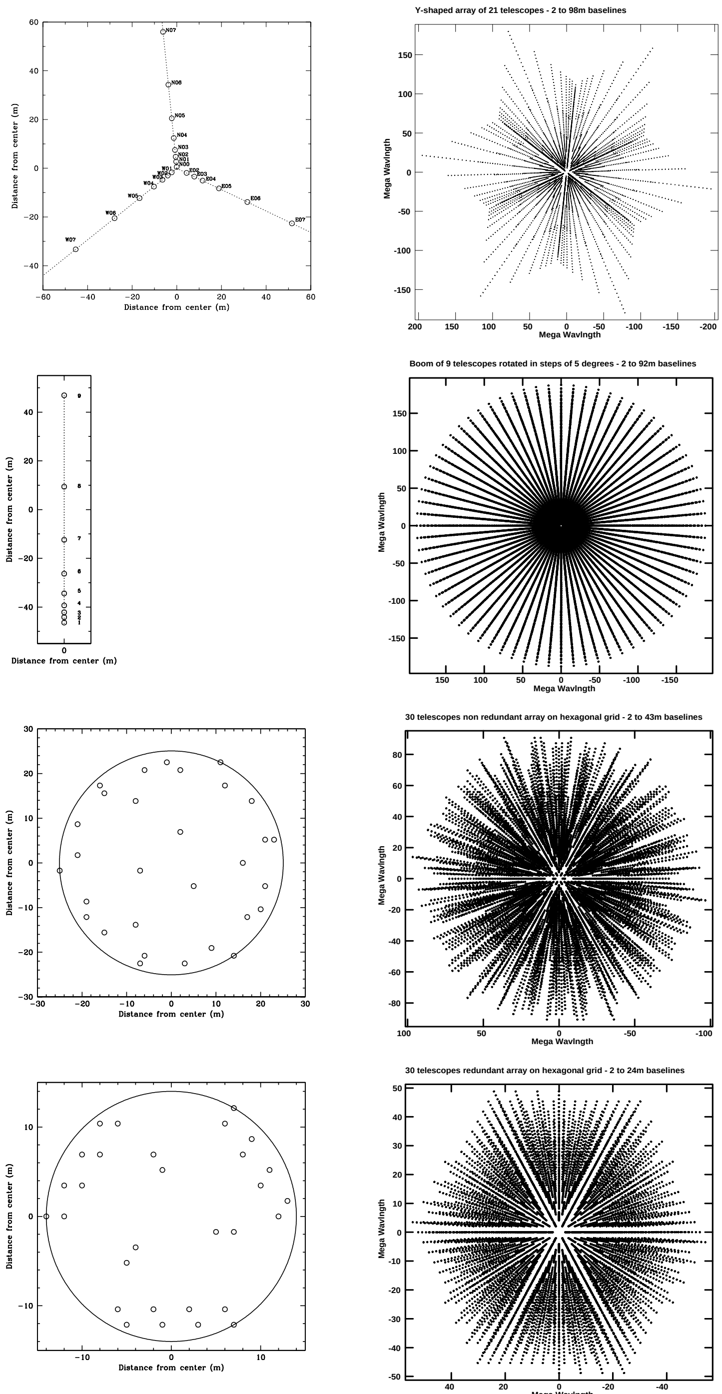

Figure 2. Array layouts (left) and their corresponding uv plane coverages (right). The figure shows, from top to bottom, the Y-shaped array, linear boom, non-redundant and redundant hexagonal grid arrays.

the fact that in the case of the longer baselines the Y-array has a better uv-coverage, while in the case of shorter baselines the boom has a better uv-coverage. The best images obtained by our simulations are the ones from the non-redundant and the redundant arrays of 30 telescope, mostly because of the large number of baselines and the dense coverage of the uv-plane.

A summary of the results from Figs. 3,4 is presented in Tab. 1, which gives the dynamic range and image rms for the 6 simulations studied here. We define the dynamic range as the ratio between the peak flux to the background rms of the synthesized image, while the image rms is obtained by dividing the rms of the difference between the synthesized and true images, only in regions covered by the satellite, by the average satellite flux in the true image. In most cases we get an image rms of the order of 10-20%, with the clear exception being the boom of 9 telescopes with maximum baseline of 92 m. The dynamic range of most images is ∼100, with the non-redundant and redundant arrays of 30 telescopes producing better results than the Y-array.

Table 1. Synthesized image properties

Array	Max. Basel.	Dyn. Range	RMS
	(m)		(%)
Y-shaped 21 telescopes	98	61.4	17.4
Boom 9 telescopes	92	221.5	49.5
Non-redundant 30 telescopes	43	169.7	11.3
Redundant 30 telescopes	24	407.7	11.1
Y-shaped 12 telescopes	22	49.0	17.1
Boom 6-telescopes	20	333.8	7.2

4. CONCLUSIONS

We presented six sets of simulations of optical interferometric observations of a geostationary satellite. These simulations show that even an array with a maximum baseline of ∼20 m is capable of imaging a satellite with a resolution of ∼1 m and detect a large amount of details. We found that short baselines, of the order of 2 m, are needed in order to image the large scale structure of the satellite, while longer baselines are needed to obtain more refined images. The number of telescopes and the shape of the array have some influence on the fidelity of the final image. Some of the best images were obtained with a redundant and non-redundant array of 30 telescopes. This result is due to the very good coverage of the uv-plane obtained by these arrays. We also find that the movable boom is not a very good design, since it requires a large number of positions in order to cover the uv-plane. Since the satellites can change appearance as a function of solar angle, this will introduce issues in the image reconstruction process.

ACKNOWLEDGMENTS

Basic research at the NLR is supported by 6.1 base funding.

REFERENCES

1. Armstrong, J. T., Mozurkewich, D., Rickard, L. J., Hutter, D. J., Benson, J. A., Bowers, P. F., Elias, II, N. M., Hummel, C. A., Johnston, K. J., Buscher, D. F., Clark, III, J. H., Ha, L., Ling, L.-C., White, N. M., Simon, R. S., 1998, ApJ, 496, 550
2. Hindsley, R. B., Armstrong, J. T., Schmitt, H. R., Andrews, J. R., Restaino, S. R., Wilcox, C. C., Vrba, F. J., Benson, J. A., DiVittorio, M. E., Hutter, D. J., Shankland, P. D., Gregory, S. A. 2011, Applied Optics, 50, 2692
3. Jorgensen, A. M., Schmitt, H. R., Mozurkewich, D., Armstrong, J. T., Restaino, S., Hindsley, R. B. 2011, Advanced Maui, Optical and Space Surveilance Technologies Conference

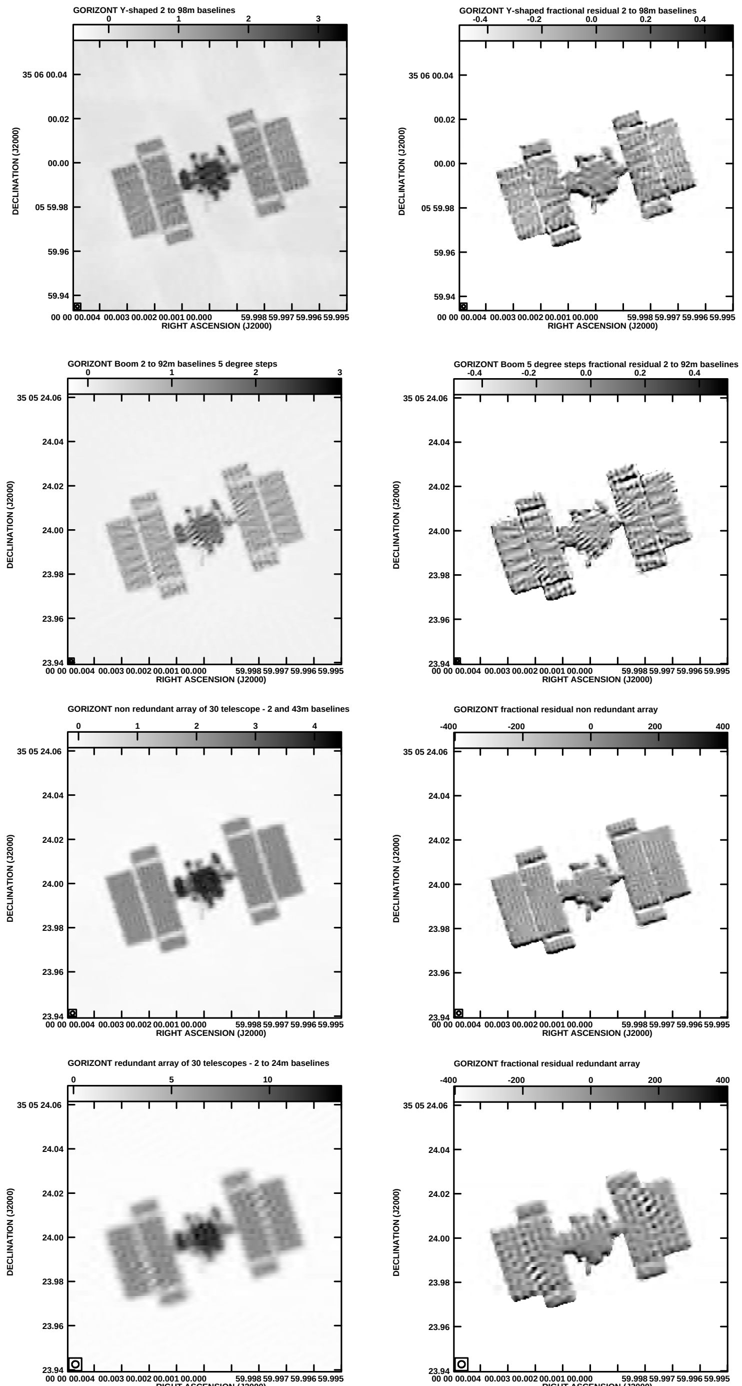

Figure 3. Comparison between the synthesized images (left) and the fractional residual images (right) for the arrays presented in Fig. 2.

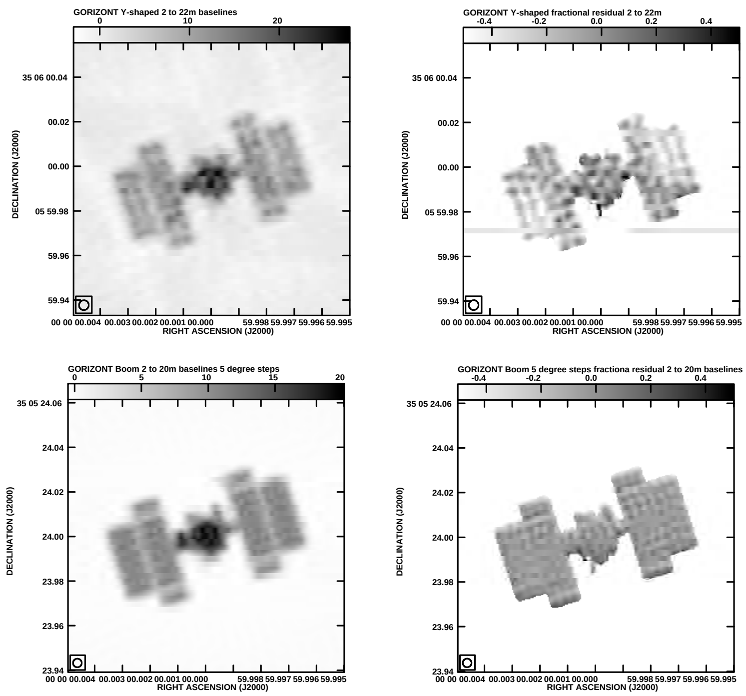

Figure 4. Same as Fig. 3 for the case of a Y-shaped array with 12 telescopes and a boom with 6 telescopes, with maximum baselines of ∼20m.

4. Mozurkewich, D., Armstrong, J. T., Hindsley, R. B., Jorgensen, A. M., Restaino, S. R., Schmitt, H. R. 2011, Advanced Maui, Optical and Space Surveilance Technologies Conference
5. Schmitt, H. R. Mozurkewich, D., Restaino, S. R., Armstrong, J. T., Baines, E. K., Hindsley, R. B., Jorgensen, A. M., SPIE Conference Series 8165A
6. van Moorsel, G., Kemball, A., Greisen, E., Astronomical Data Analysis Software and Systems V, Ed.s G. H. Jacoby & J. Barnes, Astronomical Society of the Pacific Conference Series, Volume 101, p. 37 (1996)